# PAPERS

# Fallout from Chernobyl and incidence of childhood leukaemia in Finland, 1976-92

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**Abstract**

***Objective*—To assess effects of fallout from Chernobyl on incidence of childhood leukaemia in Finland.**

***Design*—Nationwide cohort study. External exposure measured for 455 Finnish municipalities with instruments driven 19 000 km throughout the country. Values specific to municipalities corrected for shielding due to houses and fallout from A bomb testing. Internal exposure estimated from whole body measurements on a random sample of 81 children. Mean effective dose for two years after incident calculated from these measurements. Data on childhood leukaemia obtained from Finnish cancer registry and verified through hospitals treating childhood cancers.**

***Setting*—Finland, one of the countries most heavily contaminated by the Chernobyl accident; the population was divided into fifths by exposure.**

***Subjects*—Children aged 0-14 years in 1976-92.**

***Main outcome measures*—Standardised incidence ratio of childhood leukaemia and relative excess risk of childhood leukaemia per mSv. From incidence data of Finnish cancer registry for 1976-85, expected numbers specific to sex and age group (0-4, 5-9, and 10-14 years) were calculated for each municipality for three periods (1976-85, 1986-8, and 1989-92) and pooled as exposure fifths. Dose response was estimated as regression slope of standardised incidence ratios on mean doses for fifths for each period.**

***Results*—Population weighted mean effective doses for first two years after the accident were 410 μSv for the whole country and 970 μSv for the population fifth with the highest dose. In all Finland the incidence of childhood leukaemia did not increase 1976-92. The relative excess risk 1989-92 was not significantly different from zero (7% per mSv; 95% confidence interval −27% to 41%).**

***Conclusions*—An important increase in childhood leukaemia can be excluded. Any effect is smaller than eight extra cases per million children per year in Finland. The results are consistent with the magnitude of effect expected.**

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*BMJ* 1994;309:151-4

## Introduction

The accident at the Chernobyl nuclear power plant on 26 April 1986 resulted in the release of large amounts of radioactive material ($\geqslant 10^{18}$ Bq) into the atmosphere and in the radioactive contamination of large parts of Europe.[1] The aim of our study was to assess the effect of the radioactive fallout on the incidence of childhood leukaemia in Finland.

Finland provides an exceptional setting for studying the effects of fallout from Chernobyl for several reasons. Because of the meteorological conditions at the time of the accident, Finland was one of the most heavily contaminated countries outside the former USSR.[1] Moreover, fallout varied throughout the country, enabling comparison of populations with high and low exposure levels. Finland's highly developed infrastructure greatly facilitated the study, as precise exposure data were available from nationwide surveys and up to date data from the cancer registry, with practically complete coverage, were available from one of the oldest population based cancer registries in the world.

## Methods

Of Finland's population of five million, one million are children (0-14 years). The incidence of childhood leukaemia is 4·6/100 000/year. About 45 new cases were diagnosed annually in 1980-5.[2]

### ASSESSMENT OF EXPOSURE

Radiation exposure was estimated as the cumulative dose over the first two years after the accident (April 1986-March 1988). The external dose was determined by measuring dose rates with a germanium spectrometer and a Geiger-Müller tube. The tube was located above a car and the spectrometer in the car. Continuous measurements were made while the car was moving; thus the results for a given route represent the mean activity in that area of the country.

The car was driven about 19 000 km through all 405 Finnish mainland municipalities. Measurements were started in May 1986; by October, southern and central Finland had been covered. Measurements for the sparsely inhabited northern part of the country were completed in summer 1987.

Dose rate estimates were based on spectrometric measurements of caesium-137, caesium-134, and all short lived nuclides materially contributing to the dose. The effect of delay in measurement was eliminated by using a back calculation technique that takes into account both radioactive decay and washout effect. The influence of fallout from atomic bomb testing was avoided by calculating the calibration factor on the basis of $^{134}$Cs deposition. The procedure has been described in greater detail elsewhere.[3]

The external dose for the first two years after the accident was calculated taking into account the shielding factor based on the proportion of blocks of flats in each municipality.[4] A shielding factor of 0·18 for blocks of flats and 0·47 for low rise residential houses was used[5]; these factors were calculated on the assumption that people spent 85% of their time indoors.[6] A conversion factor of 0·7 Sv/Gy was used in calculating the effective dose equivalent rate from the air kerma (kinetic energy released in matter) rate.

The municipalities were then classified into fifths of exposure according to a predetermined protocol, the number of expected cases in 1976-85 being approximately 90 in each fifth (see table I).

Effective doses from internal radiation were assessed with whole body counting measurements. Stratified random sampling was performed to identify the subjects from the Finnish population registry, with stratification by province and sex. The subjects were 81 children aged 5-15 years and the whole body measurements were performed once or twice for each of them between June 1986 and April 1988—that is, within two years of the accident. The mean internal effective doses from $^{134}$Cs and $^{137}$Cs delivered during the two year period were calculated for each population fifth on the basis of measurements of children resident within the geographical area (fig 1).

Because the dose due to iodine is relevant mainly for the thyroid dose as opposed to the bone marrow dose, only the dose due to $^{134}$Cs and $^{137}$Cs was used. Owing to the composition of fallout in Finland, the internal doses from other radionuclides (strontium 90, actinides, etc) were negligible compared with the dose from $^{134}$Cs and $^{137}$Cs. Inhaled hot particles were not detected in the whole body counts after the accident.

The whole body counts were performed with two different measuring systems. The first was a whole body counter installed in an iron room and using four sodium iodide thallium crystals and a multi-detector scanning technique. The subject lay on a bed in the middle of a circular frame. During the scan measurement, the frame on which the detectors were installed was driven horizontally at a constant speed along the length of the subject. The second measuring system was a mobile whole body counter with a modified chair measuring device equipped with a high purity germanium detector.

TABLE I—*Radiation doses by exposure fifth among Finnish children*

| Fifth | Mean dose (μSv) External* | Mean dose (μSv) Internal | No of measurements | Total dose over two years (μSv) |
|---|---|---|---|---|
| I (lowest) | 41 | 68 | n=17 | 110 |
| II | 76 | 78 | n=17 | 150 |
| III | 170 | 100 | n=17 | 270 |
| IV | 400 | 150 | n=17 | 550 |
| V (highest) | 820 | 150 | n=13 | 970 |
| Wholecountry | 300 | 110 | (n=81) | 410 |

*Population weighted mean.

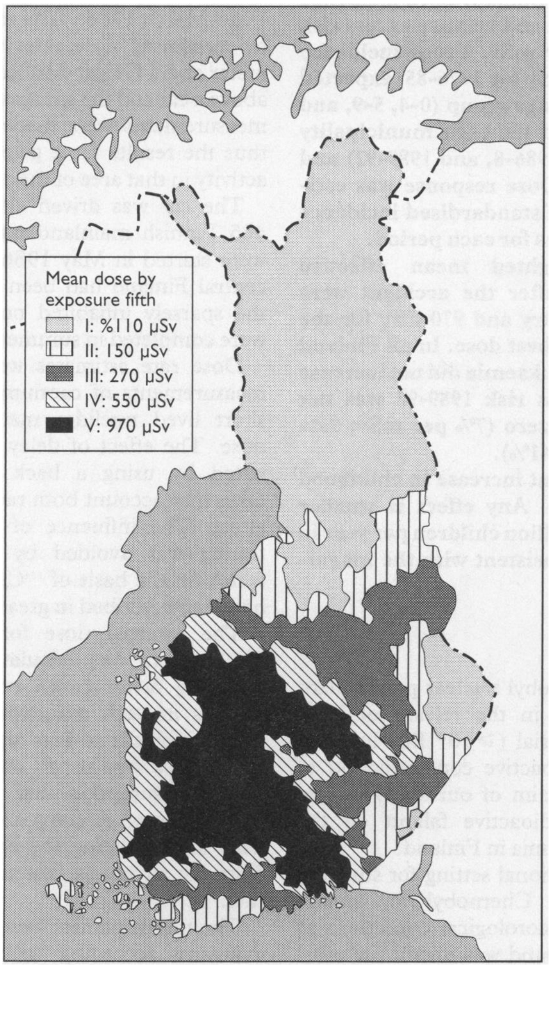


FIG 1—*Geographical distribution of exposure fifths (mean two year dose equivalent due to Chernobyl accident) in Finland*

The quantitative calibration of the whole body counters was carried out by using phantoms filled with appropriate radionuclides of known activity. The calibration factors as a function of the weight of the phantom were calculated separately for $^{134}$Cs and $^{137}$Cs. The minimum detectable activity for these nuclides was about 50 Bq.[7,8]

The internal doses were calculated by using individual body contents of $^{134}$Cs and $^{137}$Cs expressed as Bq/kg body weight. The activity time integrals expressed as Bq year/kg were calculated separately for both the nuclides, taking into account variation of body contents over time. The variation of body contents over time was determined by using data obtained from a special reference group with frequent measurements. The dose factors and the details of the dose calculation method have been published elsewhere.[7]

### POPULATION AND INCIDENCE DATA

Annual data on the child population in each municipality by sex and one year age group were obtained from the Finnish population registry. The data for 1992 were not available; they were assumed to be equal to those for 1991.

The numbers of cases of leukaemia (204 in the seventh edition of the *International Classification of Diseases*) that had occurred in children aged 0-14 years in 1975-92 were obtained from the Finnish cancer registry.[9] Completeness of registration was checked by comparing the cancer registry files with case lists obtained from each of the five university hospitals in Finland that treat all cases of childhood leukaemia. A total of 40 cases missing from the cancer registry files were identified from the hospital list. Of the cases in the study, 82% (630) were defined as acute lymphoblastic, 10% (78) as acute myeloblastic, and 2% (22) as other defined (including two cases of chronic lymphocytic leukaemia, one in the second and the other in the fifth quintile, both before 1986); the remaining 5% (35) were not accurately defined.

The expected numbers of cases were calculated for each fifth for each year on the basis of incidence by sex and age group (0-4, 5-9, and 10-14 years) in the whole country in 1976-85 and the size of the population in each age and sex stratum. Standardised incidence ratios were then calculated as the ratios of observed to expected numbers of cases.

### STATISTICAL METHODS

The data were analysed using additive Poisson regression models with an identity link for the ratio of observed to expected numbers of cases.[10] For the analysis, period was stratified into three categories (pre-Chernobyl, 1976-85; intermediate, 1986-8; and study period, 1989-92). The mean dose for each fifth was used as a numerical variable. According to the regression model, the statistical expectation of the standardised incidence ratio, E(SIR), was expressed for each period as a linear function of the dose with a common intercept, $\beta_0$, at zero dose level:

$$E(SIR)=\beta_0+(\beta_{period}\cdot dose)$$

The coefficient $\beta_{period}$ then expressed, for each period, the mean change in the standardised incidence ratio per unit of radiation exposure. The null hypothesis thus corresponds to no differences between periods nor between dose levels in any period. For comparison, multiplicative models with a log link were also applied.

## Results

The population weighted mean effective dose due to external radiation in the whole country was 300 μSv, and the mean internal dose in children was 110 μSv for the first two years after the accident (table I).

In the whole country, no clear increase in the incidence of childhood leukaemia was detected after the Chernobyl accident (table II). In the area with the highest dose, the standardised incidence ratio of childhood leukaemia increased slightly from the period before the accident (1976-85) to the study period (1989-92) (table II). The magnitude of the increase was 20% (95% confidence interval −11% to 62%) compared with the rate for the whole country in 1976-85. This finding was based on one to two extra cases a year in 1990-2, but not in 1989.

TABLE II—*Radiation dose due to Chernobyl accident and childhood leukaemia in Finland 1976-92, by period*

| Fifth | No of cases | | Standardised incidence ratio (95% confidence interval) |
|---|---|---|---|
| | Observed | Expected | |
| I (lowest): | | | |
| 1976-85 | 101 | 94·4 | 1·07 (0·88 to 1·30) |
| 1986-8 | 28 | 27·8 | 1·01 (0·70 to 1·46) |
| 1989-92 | 37 | 37·5 | 0·99 (0·72 to 1·36) |
| II: | | | |
| 1976-85 | 92 | 89·7 | 1·03 (0·84 to 1·26) |
| 1986-8 | 27 | 27·1 | 1·00 (0·68 to 1·45) |
| 1989-92 | 31 | 36·3 | 0·85 (0·60 to 1·21) |
| III: | | | |
| 1976-85 | 92 | 86·6 | 1·06 (0·87 to 1·30) |
| 1986-8 | 18 | 26·3 | 0·69 (0·43 to 1·08) |
| 1989-92 | 40 | 35·5 | 1·13 (0·83 to 1·54) |
| IV: | | | |
| 1976-85 | 89 | 92·3 | 0·96 (0·78 to 1·19) |
| 1986-8 | 29 | 26·7 | 1·09 (0·76 to 1·56) |
| 1989-92 | 31 | 35·3 | 0·88 (0·62 to 1·25) |
| V (highest): | | | |
| 1976-85 | 79 | 90·0 | 0·88 (0·70 to 1·09) |
| 1986-8 | 26 | 26·7 | 0·97 (0·66 to 1·43) |
| 1989-92 | 43 | 35·8 | 1·20 (0·89 to 1·62) |
| Total: | | | |
| 1976-85 | 453 | 453·0 | 1·00 |
| 1986-8 | 128 | 134·5 | 0·95 (0·80 to 1·35) |
| 1989-92 | 182 | 180·3 | 1·01 (0·87 to 1·17) |

An additive linear model fitted the data well (Pearson $\chi^2$=6·9, df=11). No period effect was observed (relative risk 1·01 (0·84 to 1·18) in 1989-92 compared with 1976-85). A relative excess risk of 7% per mSv (−27% to 41%) was estimated in the period 1989-92 (see fig 2). Addition of a squared dose term did not improve the fit.

The results remained non-significant when the standardised incidence ratios in different fifths of exposure were compared with those in the period before the accident, instead of comparison with a zero slope for dose (relative excess risk 18% (−15% to 52%) per mSv). A multiplicative log-linear model fitted the data equally well (Pearson $\chi^2$ 6·9, df=11) and yielded identical results.

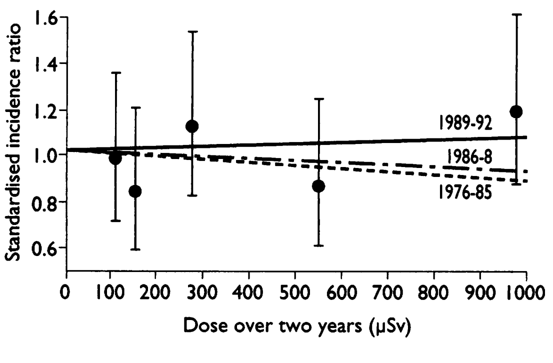


FIG 2—*Standardised incidence ratios of childhood leukaemia in population fifths with different exposure levels before the accident (1976-85), immediately after the accident (1986-8), and in 1989-92. Lines are based on regression analysis. Boxes and bars indicate mean values and 95% confidence intervals in study period (1989-92)*

## Discussion

Serious concern has been expressed about the possible long term effects on health of the Chernobyl accident, most particularly about the effect on mortality from cancer. However, projections based on existing estimates of the carcinogenicity of low doses of radiation yield a very low predicted excess in cancer mortality.[1]

Studies published so far consist of a letter reporting an increased incidence of thyroid cancer in Belarus,[11] background data of a collaborative European study on the incidence of childhood leukaemia,[12] and a letter indicating no increase in incidence of childhood leukaemia in Belarus.[13] An international panel of experts, chaired by Sir Richard Doll, has recommended that an epidemiological study of the incidence of childhood leukaemia conducted in an area with high exposure and an existing cancer registry and covering the first five years after the accident would provide the best way of checking the reliability of predictions.[14]

In several respects, Finland provides an optimal setting for studying what effects, if any, the Chernobyl fallout has had on health. It satisfies the requirements set by the expert committee of the European Commission: a relatively high level of fallout and a pre-existing cancer registry. Furthermore, it provides a clear contrast in exposure levels within the country: fallout was deposited in the densely populated southwestern part of the country, whereas the northern half was left almost untouched by the radioactive plumes.

Our study did not reveal any effect on childhood leukaemia in the whole country. However, some indication of an increase in the incidence of childhood leukaemia, one to two extra cases a year, was observed in the area with the highest exposure. Application of a linear model yielded an excess relative risk estimate of 7% per mSv; this was not significantly different from zero. This point estimate is consistent with the risk of leukaemia observed for children in Hiroshima and Nagasaki (relative risk 44 per Gy for children aged 0-9 years at exposure followed up until age of 20, which corresponds roughly to a relative excess risk of 4% per mSv),[15] although even a large deviation from it could not be excluded, including that of no effect.

The effect of radioactive fallout from the Chernobyl accident is probably so small that it cannot be shown with certainty in an epidemiological study. In our study, validity of the external exposure measurements was improved by use of a municipality specific correction for shielding effect and by elimination of the influence of fallout due to atmospheric A bomb testing. Bias in the assessment of internal exposure was avoided by using a random sample of the total child population. Thus we were able to reduce the measurement error of exposure below those available for international comparisons.[1] Nevertheless, in a single country the numbers of cases will remain small. Pooling data from several countries, as in the European childhood leukaemia incidence study,[12] will increase the number of cases. However, use of large geographical units, such as countries as a whole, may result in reduced accuracy of the exposure data. Because of lower validity of exposure measurements, the gain in power may not be as large as could be anticipated on the basis of numbers of cases alone.

Because of larger numbers of cases, adult leukaemia should also be studied. The risk of leukaemia induced by radiation may, however, be considerably smaller than among children.[15]

### SUMMARY

In summary, the mean two year effective dose

## Public health implications

- Finland, with a mean effective dose of 0·4 mSv among children over the two years after the Chernobyl accident, was one of the countries most heavily affected by the fallout
- For this study, the child population of Finland was divided into fifths on the basis of the radiation dose due to fallout
- No statistically significant effect of fallout from Chernobyl on incidence of childhood leukaemia was detected in the country as a whole, nor in the area with the highest fallout
- Even if there were an effect, its plausible maximum would be within one order of magnitude of that expected on the basis of existing risk estimates
- On the basis of the upper 95% confidence limit of the relative excess risk, an effect of eight cases or more of childhood leukaemia per year per million children in Finland (with approximately 45 cases diagnosed annually) was ruled out

equivalent among Finnish children of radiation from the Chernobyl accident was 0·4 mSv. Using the risk estimates from Hiroshima and Nagasaki,[15] the exposure corresponds to an expected effect of 0·8 extra cases of childhood leukaemia a year among Finnish children. Our point estimate (relative excess risk of 7% per mSv) yields a number of 1·3 cases per year. On the basis of the upper 95% confidence limit (41% relative excess risk per mSv), eight extra cases of childhood leukaemia a year as the true effect can be excluded. In other words, a 17% increase in incidence of childhood leukaemia in Finland was ruled out. We conclude that even if there were an effect that could not be detected in our study, it would be of little public health importance.

We thank Dr Marjatta Lanning at Oulu University Hospital, Dr Pirkko-Liisa Lähde at Tampere University Hospital, Dr Mikko Perkkiö at Kuopio University Hospital, Dr Ulla Saarinen at Helsinki University Hospital, and Professor Toivo Salmi at Turku University Hospital for provision of case lists.

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*(Accepted 14 January 1994)*

# Risk of acute childhood leukaemia in Sweden after the Chernobyl reactor accident

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*BMJ* 1994;309:154-7

**Abstract**

***Objective*—To evaluate the risk of acute childhood leukaemia in areas of Sweden contaminated after the Chernobyl reactor accident in April 1986.**

***Design*—Population based study of childhood leukaemia diagnosed during 1980-92.**

***Setting*—Coordinates for places of residence of all 1·6 million children aged 0-15 years; aerial mapped areas of Sweden heavily contaminated after the Chernobyl accident.**

***Subjects*—888 children aged 0-15 years with acute leukaemia diagnosed in Sweden during 1980-92, identified with place of birth and residence at diagnosis.**

***Main outcome measures*—Risk of leukaemia in areas contaminated after the Chernobyl accident compared with the rest of Sweden and in the same areas before the accident.**

***Results*—During six and a half years of follow up after the accident the odds ratio for acute leukaemia was 0·9 (95% confidence interval 0·6 to 1·4) in highly contaminated areas (≥10 kBq/m²) compared with the same areas before the accident. For the subgroup acute lymphoblastic leukaemia in children aged under 5 years at diagnosis the odds ratio was 1·5 (0·8 to 2·6). For all cases diagnosed after May 1986 in highly contaminated areas compared with areas of low contamination the odds ratio was 0·9 (0·7 to 1·3). For acute lymphblastic leukaemia in children aged under 5 years at diagnosis the odds ratio was 1·2 (0·8 to 1·9) in highly contaminated areas compared with areas of low contamination. Dose-response analysis showed no correlation between the degree of contamination and the incidence of childhood leukaemia.**

***Conclusion*—There has been no significant increase in the incidence of acute childhood leukaemia in areas of Sweden contaminated after the Chernobyl reactor accident.**

## Introduction

An explosion at the Chernobyl nuclear power plant on 26 April 1986 released large amounts of radioactive particles for nine days. Areas in the Soviet Union near the plant were the most heavily contaminated. Winds and rain resulted in varying degrees of contamination in different parts of Europe, especially Northern areas. The first cloud moved north west over Poland and Scandinavia. Rainfall in parts of Sweden resulted in heavy deposits of radioactive material. The most important nuclide in the fallout was caesium-137, which has a half life of 30 years. Airborne measurements of nuclide contamination were undertaken by